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Agroecological bases for the adaptation of agriculture to climate change

ABSTRACT: Although many indigenous and peasant populations are particularly exposed to the impacts of climate change and are vulnerable, some communities are actively responding to the changing climate and have demonstrated innovation and resilience, using a diversity of strategies to cope with droughts, floods, hurricanes, etc. In this article, we argue that traditional farming systems offer a wide range of management options and designs that increase functional biodiversity in crop fields, thereby enhancing the resilience of agroecological systems. Many of the traditional agroecological strategies that reduce vulnerability to climate variability include crop di- versification, maintenance of local genetic diversity, animal integration, addition of organic matter to the soil, water harvesting, etc. Several agroecologists have deciphered the agroecological principles underlying these strategies, which can be adapted by taking different technological forms (according to farm size) to design modern agricultural systems that become increasingly resilient to climatic extremes.

Keywords: Agroecology, traditional agriculture, resilience, adaptation, climate change.

Scientific and popular literature reports that -agriculture is one of the activities that will be most affected by climate change, due to the impacts that high temperatures, droughts and storms are -expected to have on plant and animal production (IPPC, 2014). It is generally predicted that -climate- change -will further aggravate the conditions experienced by peasant and smallholder farmers as a result of poverty, the sensitivity of their -geographic -locations -(rainfed areas, hillsides, etc.) and their high dependence on natural resources (Jones & Thornton, 2003). While it is true that many -indigenous and peasant -populations -are particularly exposed to the impacts of climate change and are vulnerable, many communities are actively responding to the changing climate and have demonstrated innovation and resilience, using a variety of strategies to cope with droughts, floods, hurricanes, etc. Despite -this evidence, the prevailing conclusion is that peasant agriculture is particularly susceptible because of its marginalized status and that, even if -peasants have experience in dealing with climate variability, their traditional coping strategies will not be sufficient to withstand and resist the severity of the predicted variability.

On the other hand, little is mentioned that industrial agriculture, which occupies 70-80% of the 1.5 billion hectares of global arable land (consuming 80% of oil, 80% of water and generating 20-30% of greenhouse gases) and producing only 30% of human food, is the most susceptible -to climate variability (ETC, 2017). A handful of crops are grown on the totality of this agricultural land in the form of large-scale monocultures, dangerously reducing the genetic diversity present in global agricultural systems. These intensive monoculture systems of impressive ecological homogeneity -are particularly vulnerable to climate change, in addition to pests and diseases. This -ecological- state -of susceptibility in which -industrial agriculture- finds itself -constitutes a major threat to the food security of mankind (Adams, Ellingboe & Rossman, 1971).

In this article we argue that -traditional farming systems -offer a wide range of management options and designs that increase functional biodiversity in crop fields, and thus strengthen the resilience of agroecosystems. Many of the traditional agroecological strategies that -reduce vulnerability to climate variability include crop diversification, maintenance of -local genetic diversity, animal integration, addition of organic matter to the soil, water harvesting, etc. Several agroecologists have deciphered the agro-ecological principles underlying these strategies, which can be adapted by taking different technological forms -(according to farm size) to design -modern agricultural systems that become increasingly resilient to climatic extremes.

THE VULNERABILITY OF INDUSTRIAL AGRICULTURE

More than one billion hectares of the planet is -dedicated to the monoculture of a few cereals and -animals. Wheat, maize, rice and potato alone account for approximately 60% of the world's plant-based food, and only 14 animal species provide 90% of all -animal-protein.- Genetically, modern agriculture is staggeringly dependent on a handful of varieties for its major crops (Heinemann, Massaro, Co ray, Agapito-Tenfen & Wen, 2013).

Available data indicate that crop diversity per unit of arable land continues to decline, which is partly explained by the use of more than 180 million hectares of transgenic crops (mainly soybean and maize) grown worldwide and the growing trend to produce large -monocultures of maize, sugarcane, African palm and soybeans for biofuels. Many -scientists have repeatedly warned about the -extreme -vulnerability -associated with genetic uniformity of crops, stating that ecological homogeneity in agriculture is closely linked to invasions -and outbreaks of pests and diseases.

These concerns are not new and were highlighted in 1972 with the National Research Council report "Genetic Vulnerability of Major Crops" (NRC, 1972) written by scientists who warned that tragedies such as the one caused by the corn leaf blight epidemic (Helminthosporium maydis), which resulted in an estimated 15% reduction in corn production in the Midwestern United States, could -occur in other major crops as well. There are many other historical cases that prove that the drastic reduction of crop plant diversity threatens the world's food production. The -Irish-famine -due to the destruction of the potato crop was the result of the spread of a genetically uniform clone (of a single variety, called Lumpers) and the outbreak of the -potato late- blight fungus (Phytophthora infestans) -epidemic, which caused an 80% reduction in yield. As a result, millions of Irish people starved to death and another two million emigrated. The great Bengal famine in India in 1943 was the result of a -devastating disease (Cochliobolus miyabeanus) that almost wiped out rice production. More than a century ago in France, vines were totally wiped out by -attacks of Phylloxera vertifoliae, until a -resistant cultivar -was introduced from the USA (Thrupp, 1998).

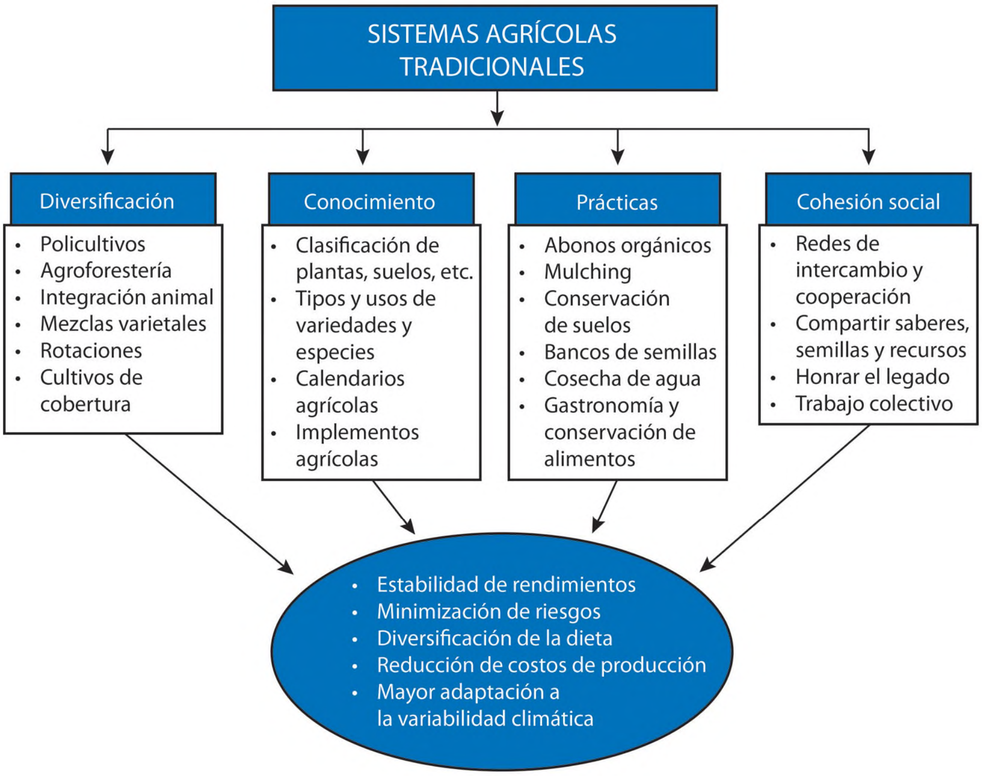
Three decades later, the issue of agricultural vulnerability is still under discussion and the debate -continues on the risk posed by agricultural homogenization (today with the expansion of transgenic crops and biofuels) when faced with climate change (Lobell & Gourdji, 2012). The susceptibility -of industrial agriculture manifested itself during the worst drought in 50 years that severely affected U.-S. crop production in 2012. It is estimated that the drought affected 26 of 52 states and covered at least 55% of the U.S. land area, or nearly one billion hectares, with substantial economic losses, and a 30% yield reduction. After four years of drought in California (2011-2015) large tracts of land (250 000 hectares) remained fallow given the lack of water, representing losses of 1 800 -million dollars and a reduction of 8 550 jobs. The -recent hurricane Irma that hit Florida caused at least a 30% decrease in yields of many crops, and winds knocked down 50% of citrus fruits, all produced in monocultures.

RESILIENT PROPERTIES OF TRADITIONAL SYSTEMS

In contrast to the monocultures of -industrial agriculture-, thousands of traditional farmers have used diversified systems such as polycultures, agroforestry -and silvopastoral systems. -There is a -positive-association -between crop diversification and agricultural productivity, farmer income, -food- security

-and nutritional wealth.

These merits are due to the ability of diversified systems to improve soil fertility, reduce pest and disease incidence, suppress weeds-, and improve system efficiency, which in turn reduces production risks and costs and allows agroecosystems to adapt to the effects of climate change (Makate, Wang, Makate & Mango, 2016). Given their socio-ecological characteristics described -in Figure 1, these systems have enabled -smallholder family farmers -to -meet their livelihood needs amid environmental variability without relying on modern agricultural technologies (Denevan, 1995). Agroforestry systems are examples of -agricultural systems with high structural complexity that have been shown to protect crops from large -temperature fluctuations by keeping them -closer to their optimum conditions. For example, shaded systems have been shown to protect coffee from decreased rainfall and -reduced soil water availability, because -tree cover can reduce soil evaporation and increase water infiltration into the soil (Lin, 2011). On the other hand, annual polycultures allow farmers to produce several crops simultaneously and minimize risks (Vandermeer, 1989). Polycultures generally show greater yield stability and less -productivity- decline -during droughts than monocultures.



TRADITIONAL FARMING SYSTEMS			
Diversification	Knowledge	Practices	Social cohesion
Polycultures Agroforestry Integration Varietal blends Rotations Cover crops	Classification of plants, soils, etc. Types and uses of varieties and species Agricultural calendars Agricultural implements	Organic fertilizers Mulching Soil conservation Seed banks Water harvesting Gastronomy and food preservation	Exchange and cooperation networks Sharing knowledge, seeds and resources Honoring the legacy Collective work
Yield stability			

Risk minimization
Dietary diversification
Reduced production costs
Increased adaptation to climate variability

Figure 1. Socio-ecological characteristics of traditional agricultural systems that confer resilience to climate change and other benefits**.**

Intensive silvopastoral systems (ISS) are a sustainable form of agroforestry for livestock production that combines forage shrubs planted at high densities, trees and palms, and improved pastures-. In -addition to ensuring a large forage biomass, these complex systems maintain a -favorable- microclimate -ensuring a high stocking rate and excellent natural milk and meat production (Murgueitio, Calle, Uribea, Calle, & Solorio, 2011).

BUILDING RESILIENCE IN MODERN SYSTEMS

For decades agroecologists have argued that a key strategy for designing -sustainable agriculture is to restore diversity to agricultural plots and surrounding landscapes and manage it more -efficiently (Altieri & Nicholls, 2004). Diversification is proposed in many ways: introducing genetic variety and increasing species diversity as in varietal mixtures and polycultures, and at different scales at the plot and landscape level as in the case of silvopastoral systems, the integration of crops and livestock, and the enrichment of the landscape matrix with hedgerows, corridors, etc., providing farmers with a wide variety of options and combinations -for the implementation of this strategy.

These diversification practices must be -accompanied by abundant additions of organic matter to create healthy soils with dynamic biological activity and good physical, chemical and biological characteristics-. Organic matter is key to resilience, as it increases the water holding capacity of the soil, increasing crop tolerance to drought. Organic matter also increases the level of infiltration to decrease runoff, preventing -soil particles -from -being carried away by water during heavy rains. Organic matter improves surface soil aggregation by holding soil particles firmly in place during rain or windstorms. Stable conglomerates -resist movement by wind or water. Organically rich soils often contain high microbial populations that influence -plant- growth -and the plant-soil-water relationship (Magdoff & Weil, 2004).

Coping with drought

Landraces: Evidence shows that landraces are less affected by environmental stresses such as drought. By making better use of available water, traditional varieties generally yield more than modern varieties under -water stress conditions. For example, in India, local wheat varieties exhibited three times higher yields relative to water use (620.94 kg ha^{-1} cm^{-1} of water) than improved wheat varieties (293.1 kg ha^{-1} cm^{-1} of water). Given this resistance, yields of local varieties are more stable than that of -modern varieties from year to year in the same field, or in several fields in the same year. The creation of community seed banks that collect the rich drought-adapted germplasm still existing in a region is therefore of strategic value for the adaptation of communities to climatic variability (Cleveland, Soleri & Smith, 1994).

Addition of organic matter to the soil: The continuous addition of crop residues, compost and the use of cover crops or green manures increase the organic matter content, which in turn -increases the water storage -capacity of the soil, improving crop resistance to drought. Depending on the soil, for every 1% increase in organic matter, the soil stores up to 1.5 liter of water per square meter. Research has shown that an increase in organic matter from 0.5% to 3.0% doubled the amount of water available to crops (Magdoff & van Es., 2000).

Activation of soil biology: Well-managed organic soil contains high populations of bacteria, fungi and actinomycetes. Bacterial populations well above 5 million individuals per gram of dry soil have been reported to help decompose -residues and make nutrients available. Among fungi, the presence of mycorrhizae (VAM), which colonize the roots of many crops, is key as they increase water use efficiency, which helps crops under water stress conditions (Augé, 2001).

Soil cover: Maintaining fallow vegetation on the soil reduces evaporation -by retaining on average 4% more water in the soil, which is equivalent to an additional 8 mm of rainfall. A study in Central America found that agroecological practices such as cover crops and mulching can increase soil water storage by 3-15%.

The conservation of water in the soil profile makes nutrients -immediately available in -synchrony with peak crop uptake periods (Buckles, Triomphe & Sain, 1998).

Polycultures: Data from 94 experiments with various associations of sorghum with pigeon pea (Cajanus cajan) -showed that for a particular "extreme event", the pigeon pea monoculture would fail once in five, sorghum -would fail once in eight, while the polyculture failed once in 36. Polycultures exhibit greater yield stability and lower yield declines than monocultures under drought conditions. When manipulated for water stress, intercropping sorghum and peanut, milo and peanut, and sorghum and milo were consistently higher yielding than monocultures at five -levels of moisture availability. Interestingly, the relative differences in productivity of -monocultures and polycultures became more pronounced as stress increased (Natarajan & Willey, 1986). In China, water use efficiency in potatoes intercropped -with beans was 13.5% higher than in monocultures (Huang etal., 2015).

Agroforestry systems: When coffee and cocoa are grown in agroforestry systems, a shade level of 40-60% of the trees creates a microclimate that -protects these crops from high temperature fluctuations and also from low rainfall by reducing water evaporation from the soil. In cases of extreme drought, many farmers, upon losing their crops, -exchange wood for food and also supplement their diets with fruits, pods and leaves from resistant trees (Malezieux, 2012).

Silvopastoral systems: Enriched pastures with high densities of forage shrubs, trees and palms can neutralize the negative effects of drought. The year 2009 was the driest year of the last 40 years in the Cauca Valley, Colombia, with a drop in precipitation of 44%. Despite a 25% reduction in pasture biomass, forage production from trees and shrubs on the "El Hatico" farm -allowed maintaining constant milk production, -neutralizing the negative effects of the drought on the entire system. However, -farmers in neighboring areas reported severe losses in milk production and animal weight, in addition to high mortality rates (Murgueitio etal., 2011).

Facing storms and hurricanes

On Central American hillsides, farmers -using diversification practices such as cover crops, intercropping and agroforestry -suffered less damage from Hurricane Mitch than their -neighbors producing conventional monocultures. Diversified plots were found to have 20% to 40% more vegetative cover, more soil moisture and less erosion, and experienced -less economic- losses -than their conventional neighbors. Banana, orange and coconut monocultures are -particularly vulnerable to storm damage, as winds -greater than 64 km hr^{-1} can cause branch breakage and root dislocation (Holt-Gimenez, 2002).

In Chiapas, diversified shade-grown coffee systems -suffered less damage from Hurricane Stan than more simplified coffee systems. In areas -affected by Hurricane Ike in Cuba in 2008, -researchers found that diversified farms exhibited productivity losses of 50% compared to 90% or 100% in neighboring monocultures, while showing faster production recovery (80% to 90%, 40 days after the hurricane) than monoculture farms (Nicholls, & Altieri, 2013). All these studies corroborate that agroforestry systems -by increasing soil organic matter improve water infiltration, by providing cover they prevent soil erosion and many trees act as windbreaks decreasing wind speed and the impact of storms. The deep and -shallow- roots -of trees also help stabilize the soil (Lin, 2011).

Polycultures of maize with pigeon pea increase -soil infiltration (which increases the water stored in the profile and reduces runoff) due to greater soil cover, and better soil structure. In -soils managed with polycultures for 5 consecutive years, infiltration increased from 6 mm hr^{-1} to 22 mm hr^{-1} and experienced less runoff (68%) than in -monocultures (94%) (Francis, 1986).

On slopes, cover crops such as Mucuna pru- riens quickly cover the soil with a lot of biomass (more than 10 Mg ha^{-1}) fixing between 90-170 kg ha^{-1} of N, on which corn is planted reaching acceptable yields -of 3.5 to 4.5 Mg ha^{-1} , avoiding erosion, in the absence of fertilizers and regardless of climatic variability. Mulching practices reduce soil exposure -to wind, and also reduce the direct impact of raindrops on the soil, which helps to reduce erosion on slopes (Buckles, Triomphe & Sain, 1998).

CONCLUSIONS

Building resilience in agricultural systems consists first of understanding the agro-ecological characteristics of traditional and other diversified systems that have withstood climatic and environmental variability (Dewalt, 1994). It is key to understand the -advantages associated with agricultural diversification that -generally reduce risks and make production more stable. The combined benefits of bio-diversified systems on water regulation, creation of a favorable microclimate, soil protection and maintenance of carbon stocks in -diversified agricultural systems not only provide environmental goods and services for producers, but -also greater resilience to climate change (Stigter, Dawei, Onyewotu & Xurong 2005). In a future where more dramatic climate swings are predicted, introducing greater diversity into agroecosystems (as traditional farmers do) can -serve as a buffer against changing rainfall and temperature patterns, and possibly -allow reversing long-term downward trends in yields as a variety of crops and -varieties respond differently to these shocks -(Altieri & Koohafkan, 2013).

The question to be addressed is to discern what principles and -mechanisms have enabled these systems to resist and/or recover from droughts, storms, floods or -hurricanes. Once the -principles that underlie the observed resilience have been deciphered, they can be applied in the -design of new systems to make them more resilient, but the technological forms the principles take will depend on the size of the farms, and the economic and environmental conditions of the farmers. The REDAGRES research network (www.redagres.org) has -produced a series of documents that provide -easy methodological tools to assess the social-ecological resilience of agricultural systems and thus strengthen farmers' response capacity (Nicholls & Altieri, 2013; Henao, Altieri & Nicholls, 2016).

Given that climate change is already exerting its effects on agriculture, an urgent step is to disseminate the resilience principles and practices used by successful farmers, as well as the results of scientific studies documenting the effectiveness of -agroecological practices that increase the resilience of agroecosystems to extreme weather events (droughts, hurricanes, etc.). Effective dissemination of -agroecological technologies will largely determine how well and how quickly farmers -can adapt to climate change. Dissemination to -farmers in neighboring communities and others in the region can be done through field days, reciprocal visits, seminars and short courses that explain how to apply agroecological principles to improve resilience to both droughts and severe storms. Perhaps the Campesino a Campesino methodology used by thousands of farmers in Mesoamerica and Cuba, which -consists of a horizontal mechanism for -information -transfer and -exchange, is the most viable strategy for disseminating agroecology-based adaptation strategies (Holt-Gimenez, 1996).

The capacity of groups or communities to -adapt to -external- social, political or environmental stresses -must go hand in hand with ecological resilience. To be resilient, rural societies must -demonstrate the capacity to buffer shocks with agroecological methods adopted and disseminated through -self-organization and collective action. -Reducing social vulnerability through the expansion and consolidation of social networks, both locally and regionally, can contribute to increasing the resilience of agroecosystems. The vulnerability of -farming communities depends on how well developed their natural and social capital is, which in turn makes farmers and their systems more or less vulnerable to climatic shocks. In regions where the social fabric has broken down, the challenge will be to rehabilitate -social organization and collective strategies in -communities, thereby increasing farmers' response capacity to implement agro-eco- logical mechanisms that will enable them to resist and/or recover from climatic events. Redesigning agroecosystems with agroecological principles leads to systems with desirable socio-ecological resilience properties.

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